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ANALYSIS OF WOOD MATERIAL RESPONSES AS MEASURED BY THREE POINTS BENDING

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Abstract: *The neck of guitar is a mechanical structure with a complex geometry which involves many operations and technological solutions with minimal materials consumption, and providing rigidity to maintain the strings tension during the playing. Meeting these requirements is an ongoing challenge for manufacturing because the wood used in the structure of the guitar neck is different as a species, as a structure, as physical-mechanical properties and rheological behavior. The paper presents the results of research conducted on samples from different types of wood: solid wood maple, glued laminated wood containing mahogany-maple-mahogany and others containing masaranduba-maple-masaranduba. The samples were subjected to the three-point bending with different intensities of loads (400, 800, 1000, 1400 N), determining for each maximum deflection and the maximum stresses. It was found that the use of laminated wood increases the rigidity of the guitar neck and the bending resistance; the most advantageous combination is masaranduba-maple-masaranduba.*
Keywords: *solid wood, glued laminated wood, guitar, three points bending, stiffness, beam of constant strength*

1. INTRODUCTION

The mechanical structure of the guitar is very complex, which is composed of both resistance elements and elements with acoustic role, or both. The guitar neck is a bar used in the structure of the guitar both for reasons of resistance and ergonomic, aesthetic and functional. The smallest area ensure the proper manipulation during the playing and the smooth, supple form of instrument coupled with the need to ensure the length of the string to the optimal functioning of the guitar. The efficiency of this type of beams is achieved when stresses from each cross-section are equal [1, 2]. Such a bar is called beam of constant strength. It should be noted that such a bar is achievable only when the structure can define one combination of loads. Thus, at rest, but loaded with forces / bending moments due to strings, the guitar neck meets the criteria of a beam of constant strength along the axe. Complexity is increasing with efforts neck structure developed during the performance, respectively while varying loads. One problem with all producers of classical guitars is the bending guitar neck, for which reason, the research on technical solutions or mechanical stiffening is still open [3, 4, 5, 6]. The paper presents the research on strength and stiffness of wood laminated compared to solid wood which are commonly used in the production of classical guitar neck.

Generally the stress and strain states of wood pieces are represented by stresses tensor and strains tensor, respectively [6, 7, 8]:

$$T_\sigma = \begin{pmatrix} \sigma_L & \tau_{RL} & \tau_{TL} \\ \tau_{RL} & \sigma_R & \tau_{RT} \\ \tau_{TL} & \tau_{TR} & \sigma_T \end{pmatrix}; \quad T_\varepsilon = \begin{pmatrix} \varepsilon_L & \frac{1}{2}\gamma_{LR} & \frac{1}{2}\gamma_{LT} \\ \frac{1}{2}\gamma_{LR} & \varepsilon_R & \frac{1}{2}\gamma_{RT} \\ \frac{1}{2}\gamma_{TL} & \frac{1}{2}\gamma_{TR} & \varepsilon_T \end{pmatrix}; \tag{1}$$

where σ_L, σ_R și σ_T are normal stresses on longitudinal (L), radial (R) and tangential (T) direction; τ_{LR}, τ_{RT} și τ_{LT} – tangential stresses in planes LR, RT și LT; ε_L, ε_R și ε_T – strains; and γ_{LR}, γ_{RT} și γ_{LT} – shearing strain. Using the tensor of elasticity modulus E and the tensor of Poisson coefficients S, results:

$$\begin{cases} \varepsilon_L = \frac{1}{E_L}(\sigma_L - \nu_{LR}\sigma_R - \nu_{LT}\sigma_T);\ \gamma_{TR} = \frac{\tau_{TR}}{G_{TR}}; \\ \varepsilon_L = \frac{1}{E_R}(\sigma_R - \nu_{RL}\sigma_L - \nu_{RT}\sigma_T);\ \gamma_{RL} = \frac{\tau_{RL}}{G_{RL}}; \\ \varepsilon_L = \frac{1}{E_T}(\sigma_T - \nu_{TL}\sigma_L - \nu_{TR}\sigma_R);\ \gamma_{LT} = \frac{\tau_{LT}}{G_{TL}}; \end{cases} \quad (2)$$

where $\nu_{LR}, \nu_{LT}, \nu_{RL}$... are coefficients of transverse contraction (first index reprezents the direction of transverse contraction and the second, the direction of the stress which produces the elongation). From energetic reason, between the coefficients of transverse contraction ν and elasticity modulus, the relations (3) are:

$$E_L\nu_{RL} = E_R\nu_{LR};\ \ E_L\nu_{LR} = E_T\nu_{TL};\ \ E_R\nu_{TR} = E_T\nu_{RT} \quad (3)$$

Substituting these parameters, we get the equations of stresses :

$$\begin{cases} \sigma_L = \frac{(1-\nu_{RT}\nu_{TR})E_L\varepsilon_L + (\nu_{LR}+\nu_{LT}\nu_{TR})E_R\varepsilon_R + (\nu_{LT}+\nu_{LR}\nu_{RT})E_T\varepsilon_T}{1-\nu_{RT}\nu_{TR}-\nu_{LR}(\nu_{RL}+\nu_{RT}\nu_{TL})-\nu_{LT}(\nu_{TL}+\nu_{RL}\nu_{TR})}; \\ \sigma_R = \frac{(\nu_{LR}+\nu_{LT}\nu_{TR})E_L\varepsilon_L + (1-\nu_{LT}\nu_{TL})E_R\varepsilon_R + (\nu_{RT}+\nu_{LT}\nu_{RL})E_T\varepsilon_T}{1-\nu_{RT}\nu_{TR}-\nu_{LR}(\nu_{RL}+\nu_{RT}\nu_{TL})-\nu_{LT}(\nu_{TL}+\nu_{RL}\nu_{TR})}; \\ \sigma_T = \frac{(\nu_{TL}+\nu_{RL}\nu_{TR})E_L\varepsilon_L + (\nu_{TR}+\nu_{LR}\nu_{TL})E_R\varepsilon_R + (1-\nu_{RL}\nu_{LR})E_T\varepsilon_T}{1-\nu_{RT}\nu_{TR}-\nu_{LR}(\nu_{RL}+\nu_{RT}\nu_{TL})-\nu_{LT}(\nu_{TL}+\nu_{RL}\nu_{TR})}. \\ \tau_{TR} = G_{TR}\gamma_{TR};\ \tau_{RL} = G_{RL}\gamma_{RL};\ \tau_{LT} = G_{LT}\gamma_{LT}. \end{cases} \quad (4)$$

Wood structure and behavior in time under various loads at a certain humidity and temperature condition gives the elastic - plastic behavior of wood. For elastic-plastic materials, the characteristic curve does not express all aspects of strain. Studies have shown that the deformation of wood and of materials based on wood, not simply an instantaneous change of form, which occurs after the application loads, but there is a continuous deformation under load, called creep (Fig. 1). Thus, the distribution of stresses in the neck of the guitar changes over time as the law of variation and position of the neutral axis, reaching into the plastic domain. Under certain conditions of humidity and temperature, under loads during time, the deformations grow, reaching the permanent strain and finally breakage [8, 9].

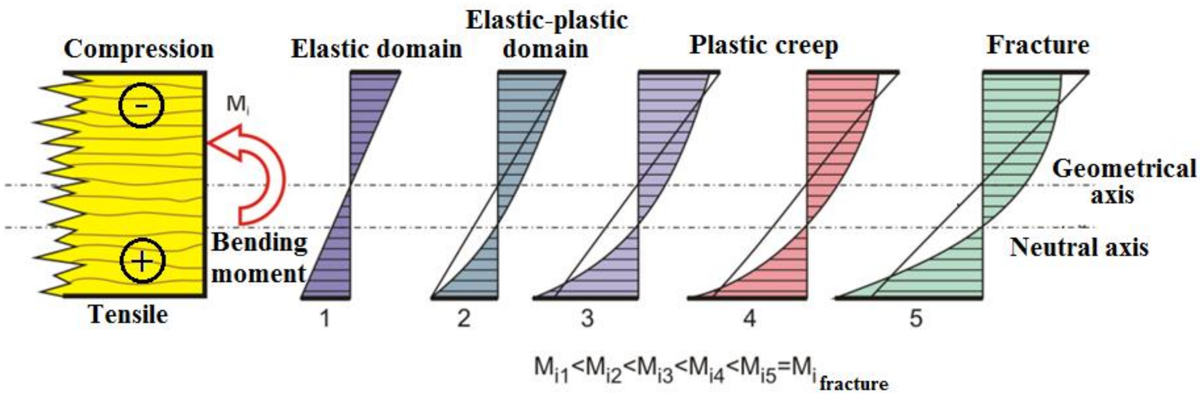


Figure 1: The variation of normal stresses from neck guitar due to creep wood, subjected to bending

2. EXPERIMENTAL SET-UP

2.1. Materials

The experimental investigations were carried out on prismatic specimens, cut in radial and tangential direction of wood, the length between supports of load machine being 200 mm and section of 20 mm x 20 mm (Fig. 2). Four samples for each type of material were tested: from solid maple (Acer pseudoplatanus), radially (coded PR_1..4) and tangential (coded (PT1..4); two specimens of laminated wood with three layers in radial direction : the core form maple and the sides from mahogany (Swietenia mahagony Jacq.) (codified MhPR1..2, MhPT1 ... 2), other two samples from the same wooden species in tangential direction and each two specimens of lamineted wood with three layers: core maple (Acer pseudoplatanus) faces Masaranduba (Mimisops globosa Gaertn.), radial and tangential (codified MsPR1 ... 2 or MsPT1..2).

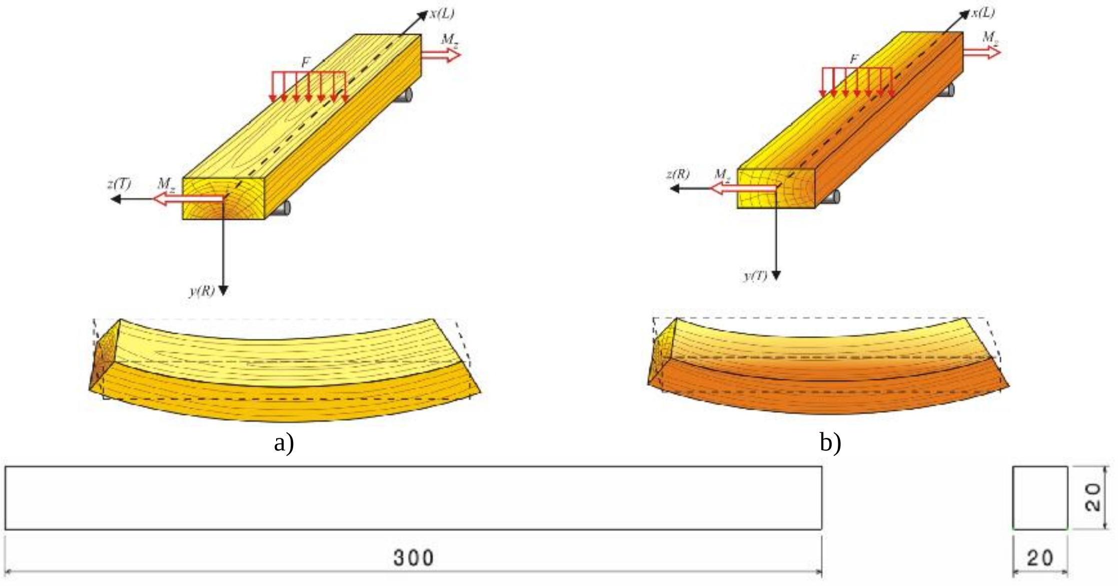


Figure 2: The representation of geometry of samples subjected to three points bending: a) tangential bending; b) radial bending

2.2. Experimental Method

The samples were tested at the three-point bending using four different intensities of bending forces (400, 800, 1000, 1400 N). For each force was measured the maximum deflection and finally the breaking force (Fig. 3). The tests were carried out on the universal machine LR5K Lloyd Instruments Plus, the force being applied at a rate of 5 mm / min (Table 1).

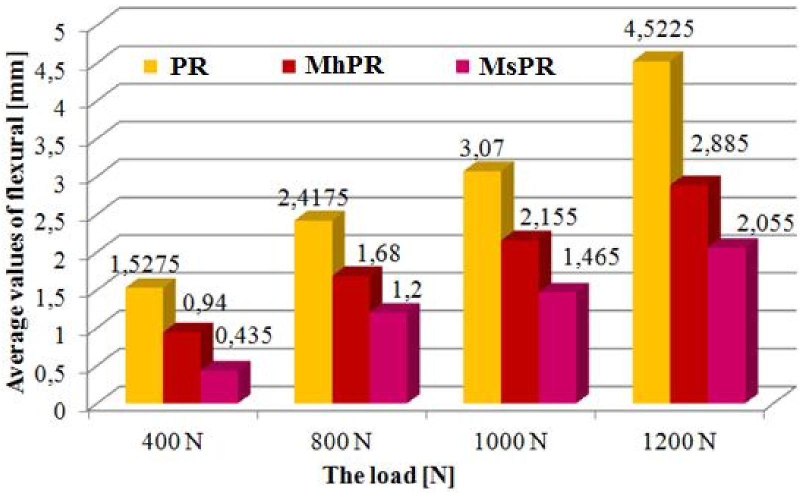
Table 1: Bending results

Samples	Flexural *[mm]*				Fracture force F_r *N*	The bending strength σ *MPa*
	400 *N*	800 *N*	1000 *N*	1200 *N*		
P_{R1}	1,6	2,5	3,1	4,48	2000	75
P_{R2}	1,38	2,6	3,3	4,6	1930	72
P_{R3}	1,1	2,13	2,5	3,51	2180	81
P_{R4}	2,03	2,44	3,38	5,5	2400	90
Average	***1,5275***	***2,4175***	***3,07***	***4,5225***	***2127,5***	***79***
P_{T1}	1,3	2,5	3	-	1000	
P_{T2}	1,1	2,35	3,2	-	1000	
P_{T3}	1,3	2,3	3	-	1000	
P_{T4}	1,27	2,15	2,63	-	1000	
Average	***1,2425***	***2,325***	***2,9575***			***37***
MhP_{R1}	0,91	1,67	2,11	2,77	2800	105
MhP_{R2}	0,97	1,69	2,2	3	2700	101
Average	***0,94***	***1,68***	***2,155***	***2,885***	***2750***	***103***
MhP_{T1}	0,85	1,57	1,94	-	1000	
MhP_{T2}	0,7	1,6	2,05	-	1000	
Average	***0,775***	***1,585***	***1,995***			
MsP_{R1}	0,5	1,3	1,6	2,15	4100	153
MsP_{R2}	0,37	1,1	1,33	1,96	4090	153
Average	***0,435***	***1,2***	***1,465***	***2,055***	***4095***	***153***
MsP_{T1}	1,1	1,3	1,48	-	1000	
MsP_{T2}	0,8	1,2	1,43	-	1000	
Average	***0,95***	***1,25***	***1,455***	-	-	***37***

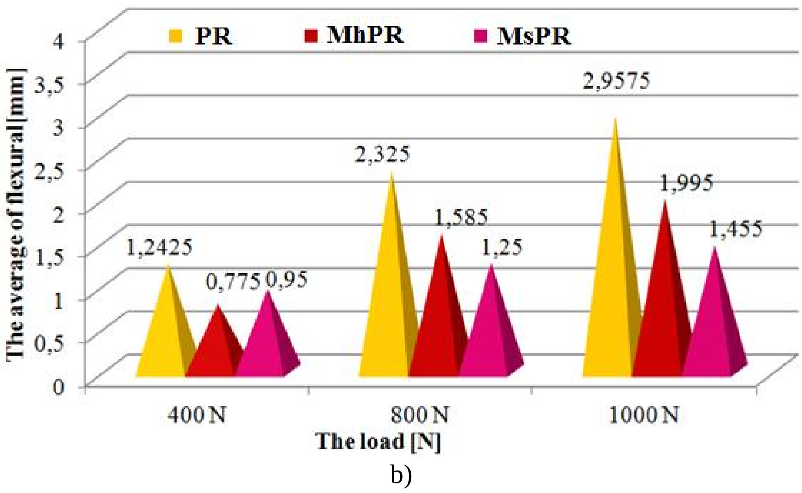
Figure 3: The samples after bending fracture

3. RESULTS AND DISCUSSION

Analyzing the values of maximum displacement in the force direction, it was found that samples from solid wood presents the greatest deflections, regardless of the applied load, which is about 120..250% higher than values obtained on laminated wood samples made from masaranduba with maple (Fig. 4 a, b). This indicates that guitar neck stiffness can be increased by using a combination of least two wood species (one with high elasticity and the other one more rigid). Masaranduba (Mimisops globosa Gaertn) is an exotic wood with density ρ_{12}= 900...1200 *Kg/m*^{3}, having the property to be very stable at atmospheric humidity variations, after being dried. In case of laminated wood with mahogany and maple, the deflections are about 56 ... 65% lower than those of solid maple, mahogany being characterized by density ρ_{12}= 500..600 *Kg/m*^{3}, fairly good stability to variations of atmospheric humidity compared with maple, whose density is arround ρ_{12}= 610 *Kg/m*^{3}.



a)



b)

Figure 4: The variation of deflection in accordance with types of tested samples: (a) radial direction; (b) tangential direction

On tangential direction, the behavior is similar to the radial direction, noting that the differences are smaller, respectively, the specimens of laminated wood containing mahogany and maple presents lower deformations around 46 ...50% compared to samples from solid maple. The samples made from maple and masaranduba recorded deformations between 31 ... 100% lower than the reference specimens (made from solid wood - maple) (Fig. 4 b). It can be concluded that the stability of neck guitar can be reached using with laminated wood the sides being from more stable wood at the climatic variation.

Regarding the breaking loads, these exceed 2 kN for specimens from solid maple, reaching the value of 4 kN for laminated wood (Fig. 5).

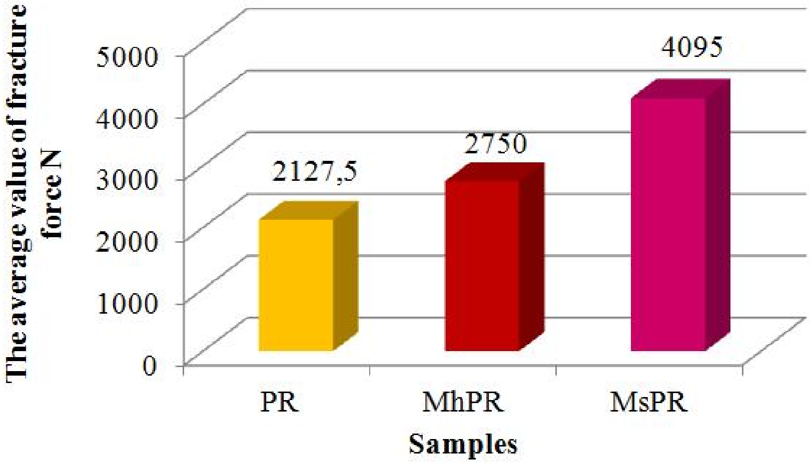


Figure 5: The variation of fracture forces for each type of samples

Analyzing the variation of flexural strength of tested samples (Fig. 6), we see that the laminated wood specimens with Masaranduba shows bending strengths of approximately 2 times greater than solid wood maple. It will be appreciated that a solution of the increasing the guitar neck rigidity is the design of a laminate beam similarly with the one described above.

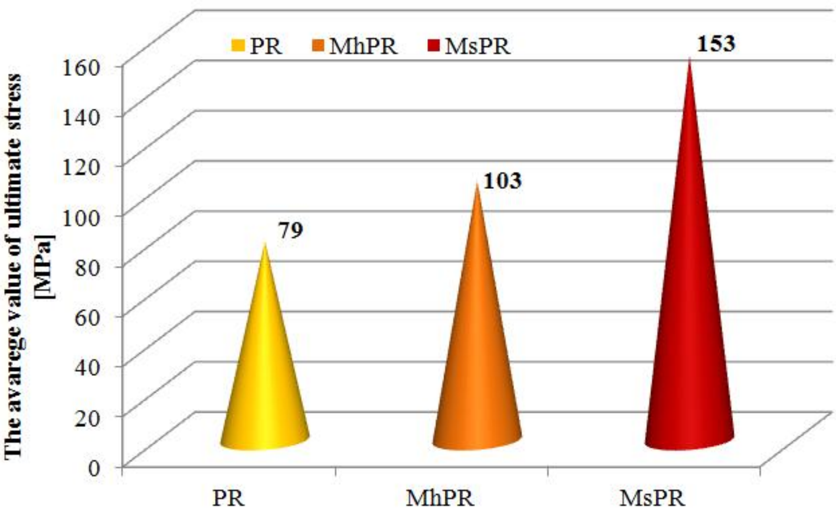


Figure 6: The variation of bending strength of tested samples

4. CONCLUSION

The paper presents the analysis of wood material responses as measured by three points bending. The symmetric combination of two wood species in a laminated wood can increase the stiffness of final samples. But, the more important of that is to find the optimum combination which can conserve the stability of product at the environmental variation because the major causes of deformation is variation of moisture contents of wood. If a musical instrument (guitar, violin, cello…) is stored in conditions of high air relative humidity, the wood from the instrument structure will tend to absorb water to achieve a moisture balance. This phenomenon leads to increasing the weight of guitar. It is known that wood moisture content for musical instruments is about 5-7%, which is obtained mainly through natural drying and subsequently through a conditioning mild to 5-7% moisture.

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